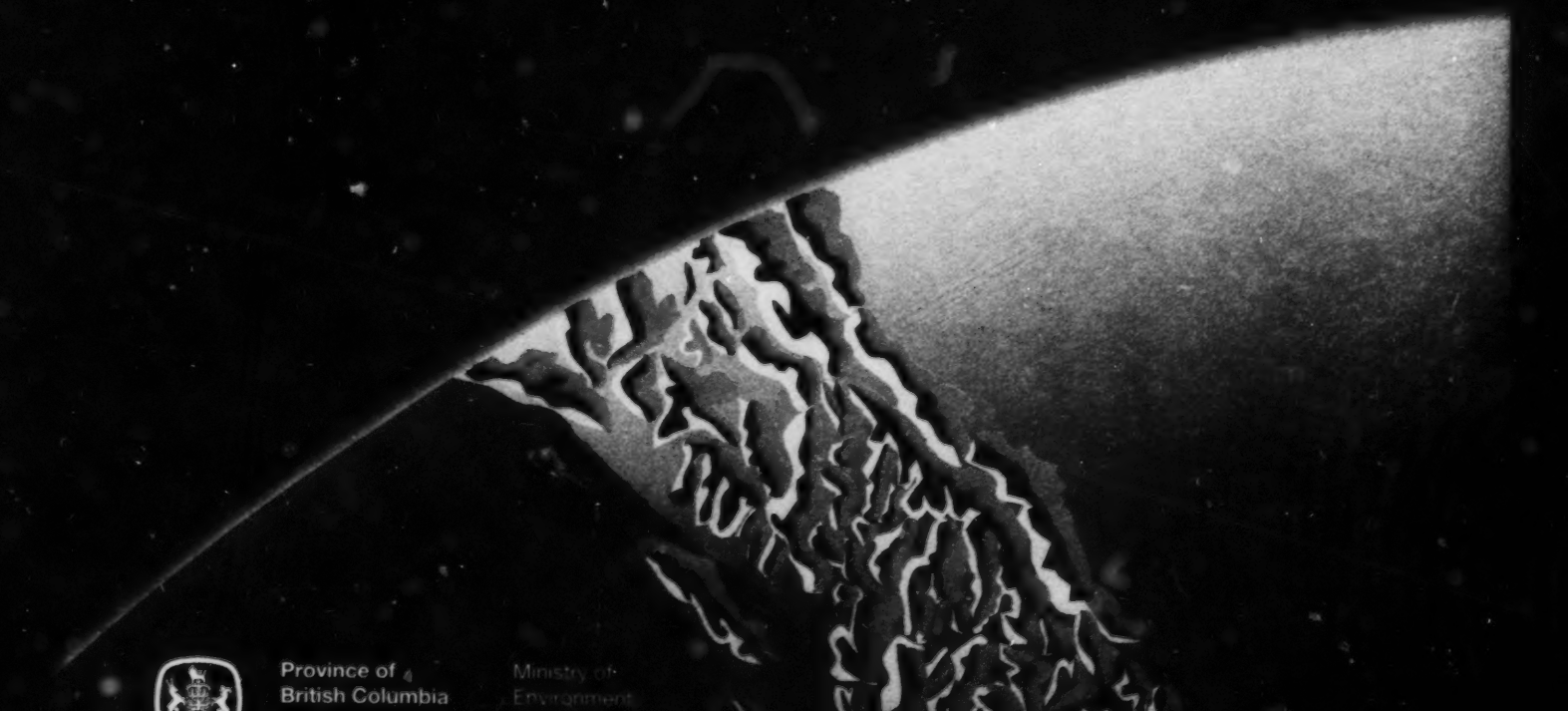
BC Environment

GREENHOUSE GAS INVENTORY AND MANAGEMENT OPTIONS:

A SUMMARY REPORT FOR BRITISH COLUMBIA



Province of British Columbia
Ministry of Environment

Greenhouse Gas Inventories and Management Options:

A Summary Report for British Columbia

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PREFACE

Ignorance is definitely not bliss when it comes to human-caused emissions of greenhouse gases. Ever since the beginning of the industrial revolution, in the 1860s, human activities have emitted increasingly large amounts of greenhouse gases into the atmosphere. But only recently have we realized the serious implications of our actions — that our greenhouse gas emissions may well be increasing the power of the earth's natural greenhouse effect.

Current scientific evidence suggests that if we continue to release large quantities of greenhouse gases, the increased greenhouse effect may cause significant alterations in the global climate, with potentially disastrous impacts. In addition, human-caused greenhouse gases contribute to other significant environmental problems, such as stratospheric ozone depletion, acid rain and smog.

We are no longer ignorant. There is growing international consensus that curbing greenhouse gas emissions is a necessity. But this knowledge is not enough. We cannot simply tell everyone to stop discharging greenhouse gases. We need to determine the sources of the emissions first. From there, we have to examine our options for reducing greenhouse gases, and pick the most effective ones. Only then will we be ready to take reasoned and productive action.

This report provides the beginning of our basis for action. It does not express provincial government policy. Rather, it lays the groundwork for discussion on the greenhouse gas management plan. It summarizes what we know about the sources of both human-caused and natural greenhouse gases in British Columbia, and describes and analyzes a range of possible management initiatives.

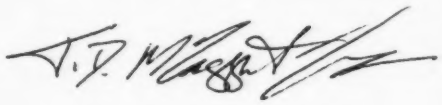
The paper is actually a summary of five in-depth studies — the first of their kind in Canada — which were prepared by private consultants under the direction of an interagency working group. The road ahead — devising a plan that will reduce greenhouse gas emissions in our province — will be no easy matter, but this research will make the travelling smoother.

A greenhouse gas management plan for British Columbia will be developed through extensive consultation with stakeholders and the public, as a crucial element of the Clean Air Strategy. The Clean Air Strategy will provide a coordinated response to the local, regional and global air quality issues facing British Columbia today.

The strategy development process is being coordinated by an interagency group, led by the provincial Ministry of Environment, Lands and Parks. Consultation meetings on the strategy — including the greenhouse gas management plan — will be carried out throughout the province during the summer and fall of 1992.

The input gathered from these provincewide discussions will be used to draft the Clean Air Strategy, which will then be reviewed with stakeholders. Once this consultation has been completed, the ministry will prepare the final Clean Air Strategy. The Clean Air Strategy will be launched publicly to allow discussion of the implementation details.

We value your input on the greenhouse gas management plan and, indeed, the Clean Air Strategy as a whole. To get involved in the consultation process, please contact the Air Resources Branch of BC Environment.



Dr. J. D. McTaggart-Cowan
Director
Air Resources Branch

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INTRODUCTION

A. The Greenhouse Effect

The theory of the natural greenhouse effect is well known by scientists — in fact, this phenomenon creates the conditions which support life on earth. Without the greenhouse effect, our planet would be approximately 32°C colder. The fact that the global population is discharging compounds into the atmosphere that may cause the atmosphere to warm is also well known. This process, known as the "enhanced greenhouse effect," is due entirely to the activities of human beings.

Currently, there is insufficient evidence to conclude that human-made (anthropogenic) emissions of greenhouse gases are causing the global atmosphere to warm. However, a 1990 report prepared by the Intergovernmental Panel on Climate Change (IPCC) summarizes the international scientific consensus: it suggests that global warming on the order of 2 to 5°C may occur in the next 50 to 100 years.

The ramifications of such changes are immense, since a warming of this magnitude is greater than anything experienced in the last 160,000 years. Present climate models predict large shifts in temperature and precipitation patterns, and increases in sea level. The potential exists for rapid changes in energy use and agricultural boundaries, as well as the possible elimination of unmanaged ecosystems. The stresses on the global socio-economic infrastructure could be disastrous.

What happens to the gases that are suspected of causing global warming after they enter the atmosphere is an uncertain and complex process. Their contribution depends both on the physical characteristics of the gases and their atmospheric lifetime.

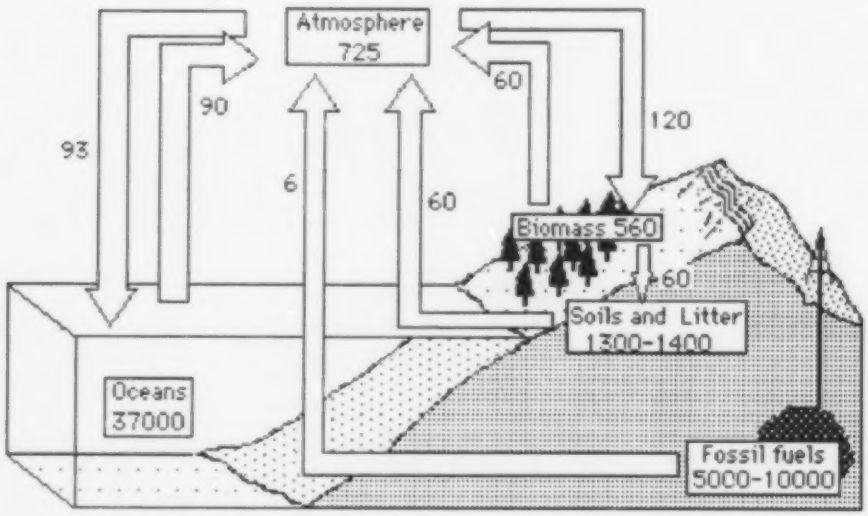
For example, the average carbon atom making up a carbon dioxide (CO_2) molecule spends its life being shunted from one place to another, in what is called the global carbon cycle. It goes from a fossil fuel to the air; from the air to the ocean; from the ocean to fish or other marine organisms; from marine life to the sea bed; and then back up to the ocean surface. From the ocean, the carbon atom returns to the atmosphere where it can be used by plants, enter the soil and possibly end up again in a fossil fuel.

The exact workings of the global carbon cycle are not completely understood. Most carbon cycle models assume that approximately one half of the carbon dioxide released into the atmosphere by burning fossil fuels stays there, the other half being absorbed by the oceans and plant life. These values, illustrated in figure 1, are not static, and there is a continuous interchange between the various carbon-storage zones. Approximately three gigatonnes (3 billion tonnes) are unaccounted for in the carbon cycle and indicate our uncertainty of the detailed workings of this complex equation.

Further examination of figure 1 demonstrates the serious ramifications of humanity's activities. If we increase fossil fuel consumption and/or remove biomass, the atmospheric carbon will rise rapidly. It is believed that the remainder of the sinks for carbon will be unable to absorb this increase.

Figure 1: Global Carbon Cycle

Values in the boxes show stored carbon in gigatonnes (10^9 tonnes); values on the arrows show the flux of carbon in gigatonnes of carbon/year.
(Source: UNEP, 1987)



The IPCC report states that "these processes are partially understood, and we are confident that the uncertainties can be reduced by further research. However, the complexity of the system means that we cannot rule out surprises."

B. Government Initiatives to Reduce Greenhouse Gas Emissions

Initiatives by the Federal Government
Internationally, Canada is taking an active role in developing a convention on climate change. The convention is to be signed at the United Nations Conference on Environment and Development in Brazil, in June 1992.

The federal government has committed Canada to stabilizing greenhouse gas emissions at 1990 levels by the year 2000. Consequently, a national action strategy has been prepared by the Canadian Council of Ministers of the Environment (CCME — representing the federal, provincial and territorial ministers of environment) to help meet this international commitment.

The key components of this strategy include:

- Limiting greenhouse gas emissions;
- Anticipating and preparing for potential climatic changes which Canada may experience as a result of global warming;
- Improving scientific understanding and increasing predictive capability with respect to climate change; and
- Developing sinks to absorb greenhouse gases.

National actions are now focused on involving other sectors in implementation plans.

Initiatives by the B.C. Government
British Columbia has begun the process of developing a Clean Air Strategy, which will address the major atmospheric problems of today — including global climate change and the enhanced greenhouse effect. The key elements of the Clean Air Strategy — the policies, initiatives and implementation details — will be developed through broad consultation with the public and interest groups.

A discussion paper, entitled *Ensuring Clean Air: Developing a Clean Air Strategy for British Columbia*, was released in March 1992 to provide a starting point for consultation on the content of this important strategy. A plan for reducing greenhouse gases will be an important part of the Clean Air Strategy. At the time of this writing (May 1992), the first consultation meeting aimed at developing a greenhouse gas management plan (called the B.C. Climate Change Workshop) is about to take place.

C. Inventories of Greenhouse Gases in British Columbia

To supply the background information needed to formulate a management plan for greenhouse gases, the province has identified the sources of greenhouse gases, as well as the management options for reducing these emissions.

This work has been carried out in two phases. First, an inventory of carbon dioxide emissions was published in May 1990. This document presented an itemization of the major sources of CO_2 — the most significant greenhouse gas.

Second, complete studies of the remaining major greenhouse gases were carried out in 1991. These inventories and possible management options are the subject of this booklet, and the process under which they were developed is described below:

An interagency group called the Greenhouse Gases Steering Committee was formed to complete inventories of methane (CH_4), nitrogen oxides (NO_x), volatile organic compounds (VOCs),ground level ozone (O_3) and stratospheric ozone-depleting greenhouse gases (such as CFCs and halons). In addition, the committee determined that management options for the control of greenhouse gas emissions (including CO_2) should be examined.

The Greenhouse Gases Steering Committee represents a cross-section of provincial government and other agencies:

- Province of British Columbia:
  - Ministry of Agriculture, Fisheries and Food
  - Ministry of Energy, Mines and Petroleum Resources
  - Ministry of Environment, Lands and Parks
  - Ministry of Forests
  - Ministry of Health
  - Ministry of Municipal Affairs, Recreation and Culture
  - Ministry of Solicitor General
  - Ministry of Tourism
  - Ministry of Transportation and Highways;

- BC Transit;
- Environment Canada; and
- Greater Vancouver Regional District.

Four consultants were hired to produce the necessary inventory and/or management options reports. Each was supervised by a subcommittee of the Greenhouse Gas Steering Committee.

In April 1992, four reports outlining the emissions sources and management options were completed and published. These inventories and management options are summarized in this paper, by including the executive summary and recommendations from each report. Their titles are:

- *Evaluation of CO_2 Management Measures* — by the ARA Consulting Group Inc.;
- *An Inventory and Analysis of Control Measures for Methane for British Columbia* — by B.H. Levelton and Associates Ltd.;
- *Ozone Depleting Greenhouse Gases in British Columbia* — by Peat, Marwick, Stevenson and Kellogg Management Consultants; and
- *British Columbia Emission Inventory of Nitrogen Oxides, Volatile Organic Compounds and Ozone (NO_x/VOC/O_3) as Greenhouse Gases* — by Concord Environmental Corporation.

The importance of the various greenhouse gases globally and provincially is shown in figure 2. The relative proportion of greenhouse gas emissions in British Columbia is significantly different from the global situation. Ozone-depleting gases such as chlorofluorocarbons (CFCs), for example, contribute only 3.1% compared to the global estimate of 24%; they will be drastically reduced as emission sources in the near future. The large portion of biomass burned in our province accounts for the 66% portion of greenhouse gases attributed to CO_2, versus 55% globally.

CO_2 has been broken into two categories — that derived from fossil fuels and that from the burning of biomass. The sources of CO_2 are separated to demonstrate that, unlike fossil fuels, the use of biomass as a fuel simply changes the time that the carbon remains in the cycle.

For example, wood chips that are burned or buried with no energy extraction will quickly move on to the next stage in the carbon cycle. If energy is extracted from this source, no additional CO_2 is emitted to the atmosphere and other sources of energy are displaced.

Currently, only a small portion of the biomass generated in the province is used as an energy source (hog fuel and pulping liquors). A large segment of this resource (e.g. woodchips at sawmills) is wasted — it is burned or sent to a landfill with no energy extraction.

This summary document is a synthesis of the major findings and recommendations extracted from the consultants' reports and is not intended to express provincial government policy. It is intended that this document will provide a foundation for further discussion, beginning with the BC Climate Change Workshop.

Editor's Note:

The science of global climate change is constantly being modified. In the brief time since the publication of our inventories, several new issues have been presented in the scientific community. While these gases represent a significant source which is not contained in the British Columbia inventory, their ozone depleting potential is zero.

A report by Abrahamson (1992) indicates that aluminum smelting may produce significant quantities of the greenhouse gases CF_4 (CFC-14) and C_2F_6 (CFC-116).

In addition, the data in the British Columbia inventories relating greenhouse gas emissions to their global warming potential are based on their direct effects. Incorporation of the indirect effects may reduce the contribution of CFCs by up to 80% (Ramaswamy et al., 1992) and the contribution of CH_4 by up to 30% (Lelieveld and Crutzen, 1992).

Figure 2A:
Global Anthropogenic Emissions of Greenhouse Gases

(IPPC, 1990)
Data Expressed as CO_2 Equivalent

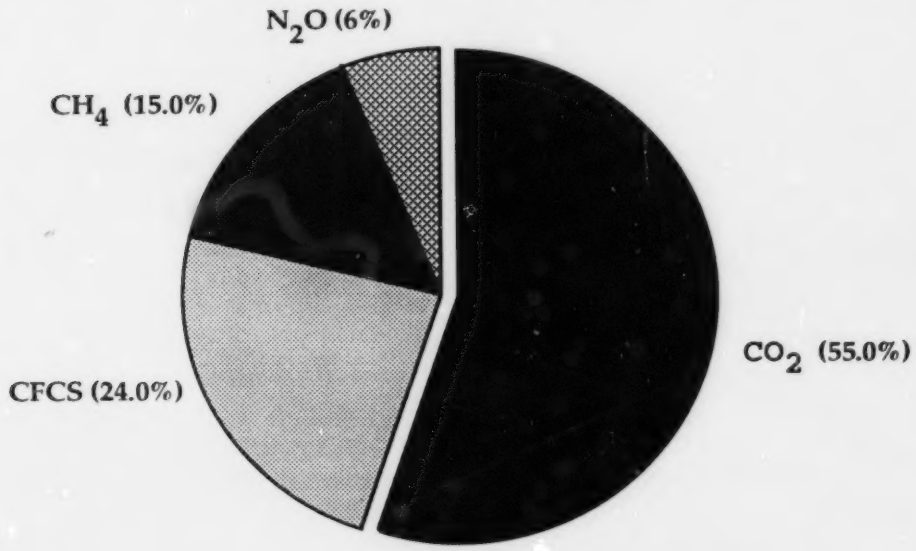
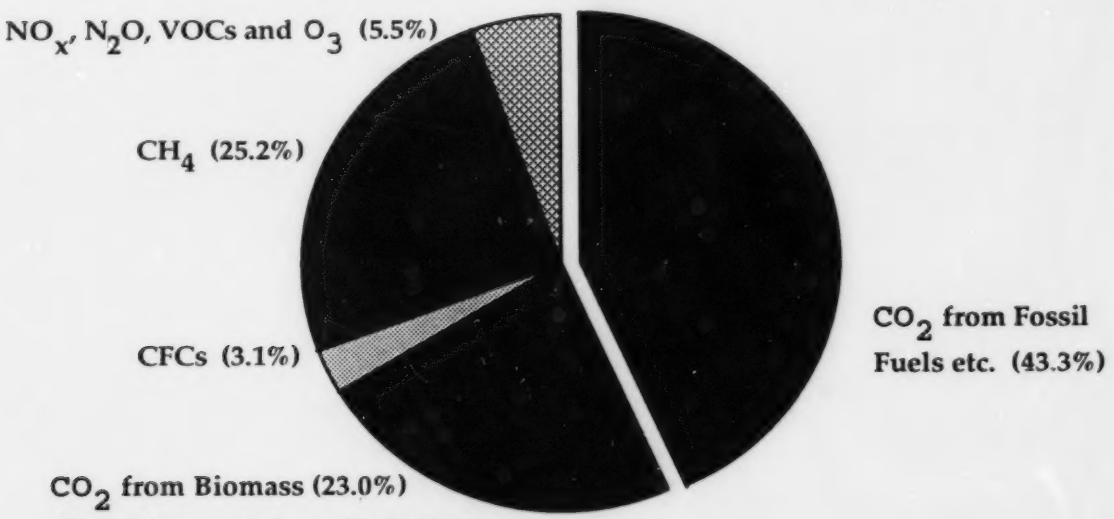


Figure 2-B:
Anthropogenic Emissions of Greenhouse Gases in B.C.



(Derived from pulp liquor, hog fuel and other wood residues.)

2

EVALUATION OF CO_2 MANAGEMENT MEASURES

A. Introduction

This chapter is based on the report prepared by the ARA Consulting Group Inc.. It was published in April 1992 and is available from Crown Publications.

This report documents the results of the evaluation of carbon dioxide (CO_2) management measures. In addition, it provides an update of the 1988 inventory prepared by B.H. Levelton and Associates in 1990. Carbon dioxide (CO_2) is a natural component of the earth's atmosphere. However, since the beginning of the industrial revolution, CO_2 levels have been steadily increasing. In British Columbia the major sources of this gas are the pulp and paper industry, prescribed burning, transportation and solid waste disposal (hog fuel and sawmill residues).

B. Objectives and Scope of the Study

The objective of the study was to develop a list of potential measures and technologies that could reduce net CO_2 emissions, and to evaluate those measures with respect to overall ease of implementation. The criteria used for evaluation were:

- CO_2 abatement potential;
- Cost effectiveness (defined as the cost of eliminating one tonne of CO_2); and
- Attitudinal, institutional, or other nonmonetary barriers to implementation.

First, a long list of measures for each sector was screened based on abatement potential and cost effectiveness. In the final assessment, which incorporated barriers

to implementation, measures were allocated to one of five categories:

1. Measures that are economic with low barriers to implementation.

2. Measures that are economic with high barriers to implementation.

3. Measures that incur moderate costs and have low barriers to implementation.

4. Measures that incur moderate costs and have high barriers to implementation.

5. Measures that may emerge from new, as yet unproven technology.

This study focuses on measures that are commercially economic; that is, measures that are economic from the perspective of the user. Differing discount rates, taxes and other price distortions can cause private and social assessments to diverge. Where these factors are important, they have been noted.

An overview of possible policy tools was also developed as a first step in developing a CO_2 strategy. However, the study stopped short of developing the CO_2 strategy; that task falls within the broader process of creating the Clean Air Strategy.

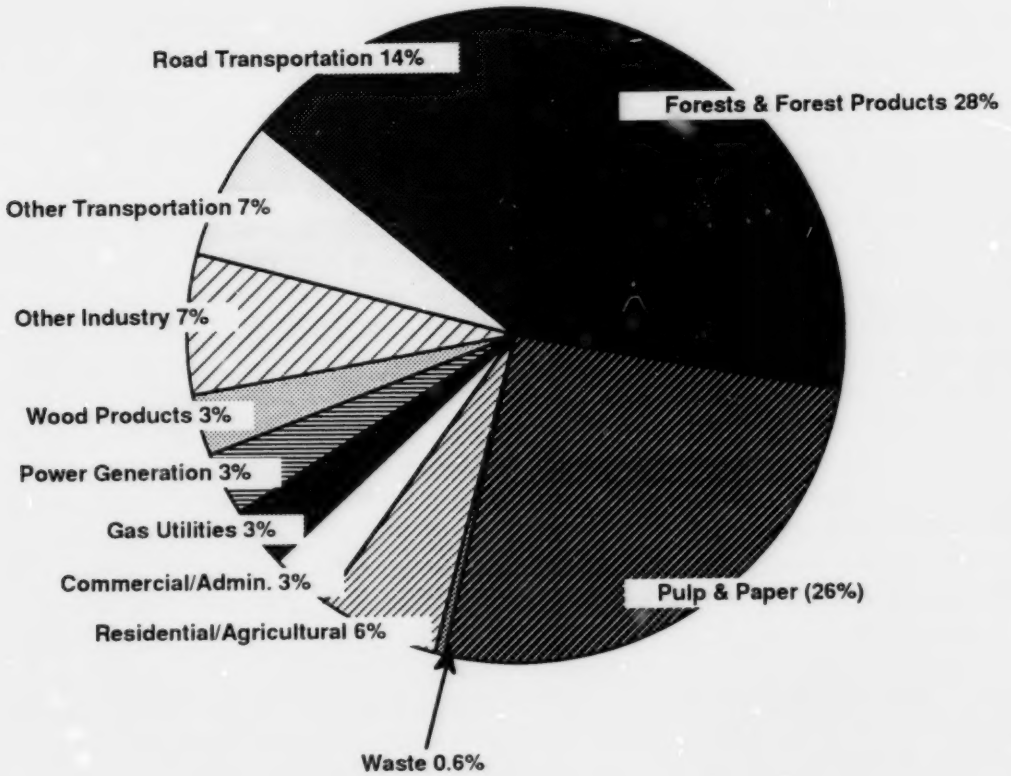
C. Sources of Carbon Dioxide Emissions in B.C.

The profile of CO_2 emissions used as a base for this study is summarized in figure 3. As indicated, emission sources are dominated by:

- Forest and forest management (prescribed burning, wood residue and forest fires);
- Pulp and paper;
- Road transportation; and
- Residential/agricultural.

These four sectors, which account for almost 75% of total provincial emissions are the focus of this study. In addition, power generation and the role of forests as a sink are addressed.

Figure 3: Sources of CO2 Emissions in B.C. (1989)



D. Management Measures

Forty-five individual measures were identified and assessed on the basis of abatement potential and cost effectiveness. The majority of transportation measures were found to be cost effective and generated moderate emission reductions. Forest and forest management measures, by contrast, had much greater abatement potential but none offered cost savings. Residential measures varied considerably with respect to cost effectiveness and abatement potential, with differences even within a measure depending on its application (e.g., single family or multiple-unit dwelling).

Measures with moderate-to-high abatement potential and moderate-to-high cost effectiveness are listed in table 1. These are considered to be promising measures. As indicated in the table, measures from all sectors are included, although residential measures are relatively under represented. Only two measures have high abatement potential *and* are likely to yield cost savings: vehicle fuel efficiency measures in the road transportation sector and general energy-efficiency measures in pulp and paper. Measures for each sector are summarized below.

Forests and Forest Management

Planting "not sufficiently restocked" (NSR) forest lands and marginal agricultural land in B.C. could increase CO_2 absorption by 4150 - 5310 kt (kilotonnes) per year or about 5% of provincial emissions. Collectively, these two measures represent one of the most promising measures from the perspective of abatement. However, the measures are costly: $1-3 per tonne CO_2 removed, or more than $650 million in total.

The incremental CO_2 absorption offered by planting NSR and marginal agricultural lands is a temporary measure. Once the lands are planted, they enter a harvest-regeneration cycle so that the CO_2 accumulation estimates noted above are valid for one rotation only (about 80 years). Nonetheless, this stop-gap measure could provide a valuable window during which new technologies or new patterns of consumer behaviour could be developed to address CO_2 emissions on an ongoing basis.

Planting NSR and marginal agricultural lands are not without their difficulties and risks. At a fairly basic level, much is still unknown about the carbon balance of temperate forests — and B.C. forests specifically. Research is underway in the B.C. Ministry of Forests and Forestry Canada, but many uncertainties linger. The figures for CO_2 absorption above are based on preliminary estimates of carbon uptake and other variables and, therefore, are subject to confirmation. In addition, there is concern that global warming itself may compromise growth and survival rates and, consequently, CO_2 absorption capability.

Incineration of harvest residues and wood residues represents a major source of emissions in the province. No conclusions were drawn regarding the role of slash burning in CO_2 management, because site-specific factors preclude generalizations. However, the use of harvest and wood residues (the latter from wood products, and pulp and paper operations) to produce energy or alternative, durable end products could significantly reduce emissions. For example, a 10% diversion of residues annually could reduce provincial CO_2 emissions by some two million tonnes per year or 2.3%.

Table 1: Promising CO_2 Management Measures

Measure	Annual Abatement Potential (kt)	Cost-effectiveness ($/tonne)	Barriers to Implementation	Category*
Forests & Forest Management				
Utilization of harvest residues & wastes	2210+	M	H	IV
Plant NSR lands	2360-3020	M	L-M	III
Plant marginal agricultural land	1790-2290	M	M	III
Pulp and Paper				
General efficiency measures	4400	H	L	I
Process changes	1945	M	H	IV
Substitution to natural gas	445	H	L	I
Substitute to 100% self-generated fuels	3805	M	M-H	IV
Transportation				
Driver training	515	H	L-M	I
Route & traffic planning	765	H	M	I
Vehicle maintenance	540	H	L	I
Conversion to natural gas	955	H	M	I
Conversion to propane	895	H	M-H	II
Public transportation	485	H	M-H	II
Trip reduction measures	580	H	M-H	II
Vehicle fuel efficiency	2010	H	M	II
Residential				
User education / practices	530	H	L	I
Passive solar (space heating)	1415	H	M	II

Source: Exhibit 9.1 and ARA Consulting Group

***Definitions:**

Timeframe:
- S: Short-term — within 5 years
- M: Medium-term — 5-10 years
- L: Long-term — after 5 years

Note: Refers to time at which measures begin to affect carbon dioxide emissions / fixation.

Abatement Potential:
- L: Low — <0.5% of 1989 provincial emissions
- M: Moderate — 0.5% to 2% of 1989 provincial emissions
- H: High — >2% of 1989 provincial emissions

Cost-effectiveness:
- L: Low — >$10 / tonne CO_2
- M: Moderate — 0-$10 / tonne CO_2
- H: High — <$0 / tonne CO_2

Barriers:
- L: Low
- M: Moderate
- H: High

Category:
- I Measures that are *cost-effective* (i.e. generate savings) with *low barriers* to implentation
- II Measures that are *cost-effective* with *high barriers* to implementation
- III Measures that have *marginal costs* with *low barriers* to implementation
- IV Measures that have *marginal costs* with *high barriers* to implementation

It must be noted that increased utilization of residues does face considerable technological and market challenges. Although various reports suggest product opportunities exist, industry representatives seriously question these conclusions, citing high risks associated with new product introduction and cost factors.

The role of forests as a store of carbon underscores the importance of judicious harvesting and attentive regeneration. Corollary measures include greater use of fibre in durable products to "lock in" carbon over the long term, and improved efficiency of fibre use — but neither abatement potential nor cost effectiveness could be quantified in this study.

Intensive forest management practices and urban tree planting were not included in the list of promising measures because they are not expected to significantly reduce emissions.

Pulp and Paper

The pulp and paper sector is the single largest energy user in the province and, based on that energy profile, is one of the main sources of CO_2 emissions. Since the first oil crisis, the industry has made better use of byproducts — such as wood residues and pulping liquor — as replacement fuels for oil and natural gas. This has helped reduce CO_2 emissions.

Further opportunities for substitution exist, both in terms of continued substitution of oil by natural gas, or of oil and natural gas by self-generated fuels. As indicated in table 1, substitution to 100% self-generated fuels could reduce emissions by almost four million tonnes per year, or 4% of the provincial total.

Also, it seems reasonable to conclude that a continuation of the general efficiency measures of the past two decades is possible, although the rate of implementation will depend on energy prices and other priorities of the industry. Such a trend could reduce emissions by some 4400 kt per year (4.7% of provincial emissions) while generating cost savings.

Although barriers to these measures have been characterized as low, they do exist. Specifically, the current poor financial health of the industry has tightened cash constraints, and compromised the ability and advisability of raising funds to undertake energy conservation projects, even though they may be economically sound in the long term. Moreover, many industry representatives accord a relatively low priority to the CO_2 issue, partly because of the urgency of other environmental matters, such as compliance with new federal and provincial effluent regulations.

Process changes include diversion from kraft to recycle or mechanical pulping

techniques. Recycle and mechanical pulping offer opportunities for significant reductions in CO_2 emissions because:

- They are considerably less energy-intensive; and
- They generate a smaller amount of wood residues and pulping liquors that require disposal.

However, process changes generally require considerable investments that can approach levels required for new mills. Process changes also, by definition, change the final product.

The decision to move to mechanical or recycle pulp is therefore complex and must take into account an array of market factors and risks. In the case of recycle pulp, the potential for substitution from kraft production is limited by the availability of raw material — in this case, post-consumer paper. While some potential for recycled pulp exists in B.C., the transportation economics of bringing post-consumer paper here for processing do not lie in the province's favour. For these and non-CO_2 environmental reasons, barriers to process changes are considered to be high.

Transportation

The road transportation sector is one of the largest oil-consuming sectors in the Canadian economy. Considerable research, particularly in California, has focused on "weaning North Americans from their love affair with the automobile," and has resulted in a fairly rich body of energy conservation opportunities. Promising measures in the road transportation sector include vehicle efficiency, traffic management, trip reduction and interfuel substitution measures.

Although some people believe that the internal combustion engine is facing inherent performance limits, much of the literature suggests that further improvements in fuel efficiency are possible — through weight reductions, improvements to aerodynamics, and engine and drive train modifications.

The measure examined in this study — a 17% improvement in average fleet efficiency — generates significant emission reductions and cost savings. The primary barriers associated with vehicle efficiency improvements are consumer preferences (affected in part by oil prices) and the limited ability of a single jurisdiction such as B.C. to influence global vehicle-design decisions.

Energy conservation and emission control through trip reduction measures have received considerable attention in California (Regulation XV) and other U.S. municipalities. The City of Vancouver is also considering such measures as part of its air quality program.

The basic principle behind trip reduction measures is changing incentives that influence employees' choice of transportation modes. In general, several individual measures — such as parking policies, ridesharing programs and promotion of public transportation — are combined into a trip reduction plan.

By increasing average vehicle ridership (AVR), California's Regulation XV expects to reduce daily trips by 750,000 and vehicle miles per day by some 15 million. The measure examined in this study — parking and rideshare measures to increase AVR from 1.3 to 1.5 people — could reduce emissions by about 600 kt per year (less than 1% of provincial emissions).

Like public transportation, trip reduction measures require changes in lifestyles that may compromise flexibility, independence and convenience. Consequently, moderate to high barriers could impede implementation of trip reduction and similar measures.

The conversion of vehicles to alternative transportation fuels could yield abatement benefits. Based on "best guess estimates" on a life cycle basis, propane and CNG (compressed natural gas) could reduce CO_2 emissions by about 1% of provincial emissions. With today's retail price structure, conversion to either fuel would provide cost savings, although the attractiveness of conversion to natural gas is partly driven by its exemption from the provincial road tax.

The main barrier to conversions is the technical uncertainty surrounding the emission performance (e.g. CO_2 and VOC) of alternative fuels . Other barriers include performance, availability of fuel, as well as safety and environmental considerations.

Ethanol and hydrogen fuels may offer more significant abatement opportunities in the future, but the technology is as yet unproven. Electric vehicles, which have received considerable attention in California's clean air strategies, also show promise, but infrastructure and battery problems hamper commercial introduction. Californian regulations that set a target for "zero-emission vehicles" — 2% of annual car sales by 1998 — will maintain pressure to solve these problems.

Residential Sector

Only two residential measures are included in the list of promising measures: user education/practices and passive solar for space heating. User education/practices encompass a package of behavioral adjustments, such as lowering thermostat settings, and housekeeping items to prevent heat loss. The main concern with implementation of this measure is finding the most appropriate and effective vehicle for public education.

More extensive application of passive solar could generate emission abatement of about 1400 kt per year, or 1.5% of provincial emissions, arising primarily from substitution of natural gas.

Barriers to implementing this measure are financial, institutional and attitudinal. For example, consumers are not generally knowledgeable about the potential benefits of passive solar, nor about available technologies. Furthermore, solar practices require home/building owners to make up-front capital investments on their own account — rather than including the costs in fuel payments (oil, natural gas or electricity) and spreading them out over many years.

The attractiveness of other residential energy conservation measures — such as direct solar for water heating and building-envelope retrofits — vary considerably among applications. But generally they do not yield a sufficiently potent combination of abatement potential and cost effectiveness to include them on the list of promising measures.

The most effective management measures, in terms of reducing CO_2 emissions in the residential sector, are also the most expensive. Conversion of light fuel oil (LFO) and natural gas to electricity could reduce emissions by more than 3850 kt per year (4% of provincial emissions) assuming today's mix of power sources. However, the cost of such conversions would exceed $20 per tonne CO_2 reduced.

Power Generation

Hydroelectric power represents a significant resource that reduces B.C.'s CO_2 emissions well below those in jurisdictions that rely on coal, oil and natural gas. However, the dominance of hydro limits opportunities for further reducing CO_2 emissions from the electrical generating sector. Some reduction could be garnered by eliminating the use of the Burrard thermal plant, but this option could hamper the utility's capability to satisfy peak demand. Alternative energy sources (e.g. wind) are still considered a long-term proposition.

Some of the CO_2 management measures discussed in other sectors focus on converting from oil, natural gas, etc. to electricity. They also raise the question about B.C. Hydro's likely response to an increase in demand. At the two extremes are a CO_2-intensive response and a hydro-intensive response. A CO_2-intensive response would meet demand by:

- Increasing purchases from Alberta;
- Reducing exports to the United States and Alberta; and

- Using the full capacity of the Burrard thermal plant.

The sources could meet demand increases up to about 15% of projected loads, resulting in an emission factor for electricity of about 60 t/TJ compared to the current system average of 12 t/TJ (where 1 TJ = 1 trillion joules or 10^{12} joules).

The hydro-intensive response would use hydro potential to its maximum and would result in an emission factor for incremental electricity supply of less than 4 t/TJ (for a 10% increase in demand). The pace of demand increases is, however, central to the viability of the hydro-intensive option. Should demand increase rapidly (e.g., 20% by 1995/6), sufficient hydro resources could not be made available and some CO_2-intensive options would be required.

Resource management decisions by B.C. Hydro can, therefore, affect the CO_2 abatement potential of conversions to electricity and, conversely, measures that promote conservation of electricity. The estimates of CO_2 abatement from fuel switching that are presented in the main body of this report assume a supply response that favours hydro, but does not reflect the maximum reductions possible if a hydro-intensive strategy were followed.

Relative to these estimates, a CO_2-intensive supply response would increase the attractiveness of electricity conservation measures and decrease the attractiveness of conversions. Results of a sensitivity test using an electricity emission factor of 60 t/TJ indicate that conversions of natural gas and LFO to electricity in the residential sector could still generate emission reductions, but at minimal levels and with a further increase in the cost per tonne CO_2 abated.

E. Social Cost Considerations

As noted above, this study focuses on the attractiveness of individual measures from a commercial or private perspective; that is, the "economics" from the perspective of the individual/company implementing the measure. However, the costs of a measure can differ when viewed from the perspective of society as a whole for two main reasons:

- Costs are discounted as different rates reflecting different costs of capital; and

- Taxes and price regulation create a divergence between retail and social (resource cost) energy prices.

Two sets of sensitivity analyses were run to examine the implications of a social cost perspective. The only substantive changes suggested by a social-cost approach were to eliminate public transportation and conversion of private road vehicles to natural gas from the list of promising measures.

F. Policy Tools

Policy instruments — the tools by which management measures can be implemented and promoted — can be grouped into seven categories:

- Research, development and demonstration (RD&D);
- Information;
- Regulations;
- Financial incentives;
- Taxes and fees;
- Marketable permits; and
- Direct government action.

The relevance of each of these types of instruments to the management measures identified above is presented table 2. As indicated, RD&D, public education, and various financial instruments can be applied to most of the management measures. However, the appropriateness of any specific application should be assessed with respect to flexibility, ability to monitor effectiveness, information needs and administrative requirements, and distributional and equity considerations. Potential complementarities, synergies and conflicts among policy tools considered for different measures should also be evaluated.

G. Conclusions: CO_2 Management Opportunities

This study has identified a number of management measures that can reduce CO_2 emissions while generating energy cost savings. These measures are not additive because some preclude others (e.g. conversion from gasoline to propane precludes the benefits of conversion to natural gas) and potential CO_2 reductions depend on the sequence in which measures are introduced.

However, the maximum abatement potential of measures that are cost effective *and* have low barriers to implementation (Category I measures) is *generously and roughly* estimated at about 8 million tonnes CO_2 per year, or less than 10% of current emissions. These emission reductions stem almost entirely from measures

Table 2: Policy Instruments to Implement Promising CO_2 Management Measures

	RD &D	Information			Regulations		Financial Incentives			Taxes and Fees			Market-able Permits	Direct Gov't Action	
		Labels / Rating	Audits	Public Education	Perform-ance Standards	Building Codes	Tax Incentive	Low Cost Loans	Direct Payments	Energy Tax	Carbon Tax	Other Tax		Planning	Investment
Forests & Forest Management															
Utilization of harvest residues & wastes	✔						✔				✔		?	✔	
Plant NSR lands	✔			✔			✔		✔				?		✔
Plant marg. agricultural lands	✔			✔			✔		✔				?		✔
Site treatment	✔										✔		?	✔	
Pulp & Paper															
General efficiency measures	✔	✔	✔	✔	✔		✔			✔	✔		✔		
Process changes	✔						✔	✔		✔	✔		✔		
Substitute to 100% self-generated fuels	✔						✔	✔		✔	✔		✔	✔	✔
Substitution to natural gas							✔	✔			✔		✔		
Transportation															
Vehicle fuel efficiency	✔	✔			✔					✔	✔	✔	✔	✔	
Driver training				✔			✔		✔	✔	✔		✔		
Route & traffic planning	✔			✔						✔	✔		✔		✔
Vehicle maintenance					✔					✔	✔		✔		✔
Conversion to natural gas	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Conversion to propane	✔	✔		✔	✔		✔	✔	✔	✔	✔		✔		
Public transportation				4			✔			✔	✔	✔	✔		✔
Land use planning					✔	✔	✔					✔		✔	
Residential															
User education / practices			✔	✔			✔			✔	✔		✔		
Passive solar	✔	✔	✔	✔		✔	✔	✔	✔	✔	✔		✔		✔

in the area of transportation (3 million tonnes per year) and pulp and paper (5 million tonnes per year). A negligible amount is contributed by user education in the residential sector.

The two most important and cost-effective measures are:

- General energy-efficiency improvements in the pulp and paper industry (over 4 million tonnes per year, based on a continuation of energy use trends in the industry over the last two decades); and

- Improvements in vehicle fuel efficiency (about 1.5 million tonnes per year), although B.C.'s ability to influence car design is limited.

The full complement of cost-effective measures (i.e. categories I and II, including those that face high barriers to implementation) are again dominated by transportation, and pulp and paper measures — accounting for about 45% and 40% of maximum abatement potential, respectively. Residential measures contribute an additional 15%, most of which are generated by passive solar applications with significant barriers to implementation.

If the most promising programs of reforestation/afforestation are considered (category III measures), maximum abatement potential could rise to about 17 million tonnes per year, or about 18% of current provincial emissions. These planting measures are costly ($650 to $750 million or $1-3 per tonne CO_2), and questions remain about the overall long-term balance of harvesting and forest regrowth. However, the measures could afford important breathing space, during which time research, technological development and public education could generate long-term solutions to the CO_2 problem.

Additional abatement is feasible from category IV measures such as process changes in the pulp and paper industry. However, the uncertain economics of these measures combined with their high barriers to implementation suggest that abatement would fall short of the maximum potential estimated in this study.

Maximum potential emission reductions from different combinations of measures are suggested in the table 3. We emphasize that these figures are in every sense maximum potential; they overstate realizable potential because only gross overlapping of measures has been taken into account. The cumulative effects of sequenced introduction of measures have not been incorporated.

Table 3: Maximum Abatement Potential of Different Measures for British Columbia
(kt per year based on 1989 emissions)

Sector	Category I	Categories I-III	Categories I-IV
Forests		4,100-5,300	6,400-7,500
Pulp and paper	4,800	4,800	10,100
Road transportation	2,700	5,900	5,800
Residential	500	1,500	2,000
Total	**8,000**	**16,400-17,600**	**24,300-25,400**
(% prov. emissions)	(9%)	(18%)	(27%)

In summary, B.C.'s abundance of hydroelectric power and natural gas offer opportunities for CO_2 management, but are not the panacea they may appear to be at first glance. Although abundant, hydroelectric power is expensive from both economic and environmental perspectives.

The use of natural gas in the oil-dominated transportation sector faces the same barriers and problems as in other jurisdictions. In fact, the considerable switching from oil to natural gas that has occurred in B.C. in the past 20 years limits the extent of additional CO_2 abatement opportunities in the residential sector.

Based on the analysis in this study, a CO_2 management strategy for British Columbia will focus on the transportation and pulp and paper sectors. An aggressive strategy aimed at reducing emissions by more than 15% will require costly measures such as planting NSR and marginal agricultural land.

3

AN INVENTORY AND ANALYSIS OF CONTROL MEASURES FOR METHANE (CH_4) FOR BRITISH COLUMBIA

A. Background

This chapter is based on the consultant's report prepared by B.H. Levelton and Associates, published in April 1992 and available from Crown Publications.

Methane gas (CH_4) is one of several greenhouse gases that contribute to global warming. At present, the average global methane concentration is increasing by approximately 1% every year (IPCC, 1990). The present atmospheric concentration of CH_4 is more than double the preindustrial value.

Releases of methane to the atmosphere occur from natural as well as human activities. Major natural sources of methane are wetlands, wild animals and wild fires. Major global anthropogenic (human-made) sources of CH_4 are landfills, manure piles, domestic animals, natural gas systems, coal mining, rice production and fuel combustion. Of the seven major anthropogenic sources, all but rice production apply to British Columbia.

An inventory of methane emissions from anthropogenic and natural sources in Canada has been prepared by Environment Canada (Jaques, 1991). However, an inventory of methane emissions in British Columbia has not previously been prepared. One of the objectives of this study was to prepare an inventory of CH_4 emissions and sinks from both natural and anthropogenic sources in British Columbia for 1990 and 2005. Another objective was to discuss available CH_4 reduction opportunities — as well as technologies and impacts associated with the most suitable options for the top emission sources in B.C..

B. Scope of Work

The main project objectives were:

1. Prepare an inventory of methane in B.C. for both anthropogenic and natural sources for 1990. Contributions from individual source sectors were to be determined using accepted methodologies and best available statistics.

2. Prepare an inventory of methane sinks in the province for 1990.

3. Project a methane inventory for the year 2005, assuming no new policies or regulations are implemented to reduce methane emissions.

4. Develop a list of control measures and technologies that could reduce methane emissions in both the short and long term.

5. Estimate the technical potential of each measure for reducing methane emissions in the short and the long term.

6. Discuss the technologies and impacts of CH_4 reduction opportunities for major sources of methane emissions, as well as cost effectiveness and economic viability of these measures/technologies.

The inventory was organized into nine anthropogenic and four natural methane source categories. These categories are:

Anthropogenic

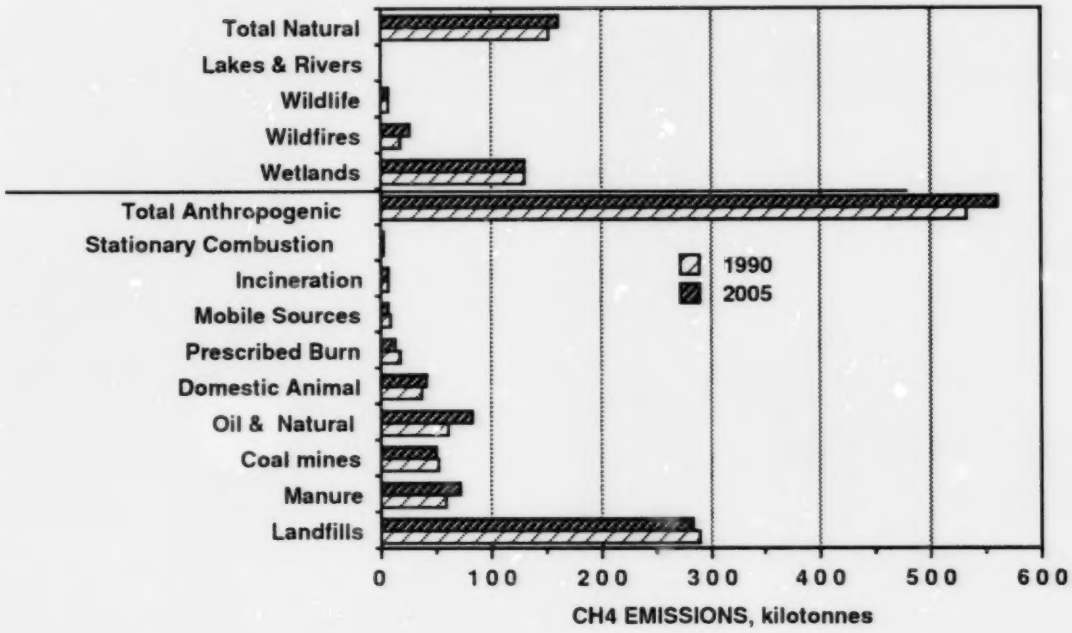
- Landfills;
- Manure;
- Natural gas industry;
- Domestic animals;
- Prescribed fires;
- Oil industry;
- Mobile combustion sources;
- Incineration; and
- Stationary combustion sources.

Natural

- Wetlands;
- Wildfires;
- Wildlife; and
- Lakes and rivers.

The majority of the information used to complete the methane emissions inventory was obtained from discussion with industry and government representatives. The provincial Ministry of Energy, Mines and Petroleum Resources (EMPR), provided most of the energy consumption estimates used for the mobile and stationary combustion sources. The cooperation received from the industry and government agencies was invaluable in making this inventory as complete and accurate as possible.

Figure 4: B.C. Methane Emissions by Source Sector



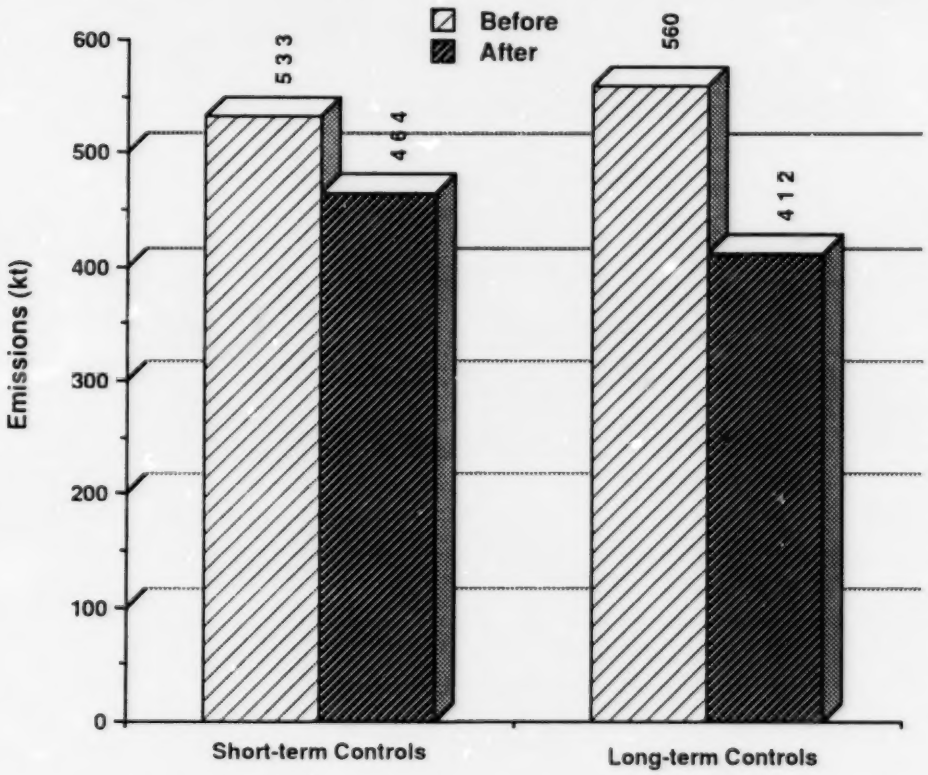
Latest emission factors were obtained from various sources — including the ad hoc committee, Environment Canada's National Methane Inventory (Jaques, 1991), U.S. EPA and Levelton Associates. Methane uptake by the atmosphere and aerobic soils for B.C. was estimated from the literature.

Annual anthropogenic and natural methane emissions in B.C. for 1990 and 2005 by major source sectors are shown in figure 4.

The top four anthropogenic methane emitters account for about 87% of the total

human-made sources for 1990 and 2005. Landfills are the largest source of CH_4 in the anthropogenic category, and wetlands the largest contributor from natural sources.

Figure 5: Methane Emission Reduction Potential for B.C.



A number of technical control measures were selected for implementation in the short and long term. Attention was given to the control measures that were thought to have acceptable economic and social impacts. The measures selected are best considered as illustrative of the levels of control possible.

The short-term and long-term reduction in methane emissions achieved by the selected control measures is depicted by figure 5. A 13% reduction relative to 1990 could be achieved in the short term. In the long term, the reduction achieved is 27% relative to emissions in 2005.

The study yielded a number of recommendations which, if implemented, would improve the inventory of methane emissions and promote the implementation of emission control measures. These may be summarized briefly as follows:

- Review the economic barriers of landfill gas recovery systems;
- Verify and develop a computer model to analyze emissions from landfills;
- Review landfilling regulations;
- Develop alternatives to reduce landfilling of wood residues;
- Develop a code of practice for the natural gas production industry;
- Conduct a detailed study to quantify fugitive emissions from the natural gas production industry;
- Conduct a detailed study of economic incentives for methane emissions control measures;
- Encourage manure treatment systems on dairy farms; and
- Conduct a detailed analysis to determine methane emissions from landfilling of wood residues and pulp mill residues to reduce the uncertainty in the preliminary estimates made in this study.

C. Conclusions

1. Annual methane emissions from anthropogenic sources for 1990 and 2005 were determined to occur in the subsectors listed in table 4.

   Landfills are the main anthropogenic source by a substantial margin, contributing 51-55% over the next 15 years. Eighty-seven percent of the anthropogenic emissions come from landfills, oil and gas production and distribution, manure and coal mining.

   Anthropogenic sources contribute 78% of the total emissions from human-made and natural sources.

Table 4: Anthropogenic Methane Emissions in B.C.

Source	CH_4 Emissions (tonnes)*	
	1990	2005
Landfills	290,500	282,900
Oil and Natural Gas Industry	60,800	83,600
Manure	58,300	72,600
Coal Mines	51,600	50,800
Domestic Animals	36,600	42,400
Prescribed Fires	17,700	12,400
Mobile Combustion Sources	9,000	7,400
Incineration	6,800	6,800
Stationary Combustion	1,000	1,200
TOTAL	532,400	560,200

* Rounded to nearest 100 tonnes. Sum may not add to the rounded total shown.

2. Natural methane emissions total 153,800 tonnes from the source categories in table 5:

Table 5: Natural Methane Emissions in B.C.

Source	CH_4 Emissions (tonnes)*	
	1990	2005
Wetlands	129,900	129,900
Wildfires	17,700	25,300
Wildlife	6,100	7,000
Lakes and Rivers	0	0
TOTAL	153,700	162,300

*Rounded to nearest 100 tonnes. Sum may not add to the rounded total shown.

Any changes in natural emissions are hard to predict due to the lack of data suitable for forecasting. The estimate for 2005 differs from the 1990 estimate primarily because of the use of ten-year average for the area burned by wildfires, which is larger than the area burned in 1990.

Natural methane emissions from the inventoried sources in 1990 are 22% of the emissions from natural and anthropogenic sources.

3. Methane emissions from landfills come from the disposal of municipal solid waste, wood residue and sludge from pulp mills — with contributions of 79%, 17% and 4% respectively, in 1990. A 3% reduction in emissions is forecast to occur by 2005 because of an expected reduction in the quantities of municipal waste landfilled in future. The emission estimates for wood residue and pulp mill residues is very approximate because of lack of data and uncertainties in the emission estimate model.

4. Dairy cattle are the primary source of emissions associated with anaerobic decomposition of manure, contributing 76% of the amount for this subsector.

5. Methane emissions occur from production, processing, transmission and distribution of natural gas. These sources emitted 43,600 tonnes in 1990, and are projected to emit 76,500 tonnes in 2005 because of growth in natural gas volumes. The majority of emissions (72%) occur from production activities.

6. Beef cattle are the main source of methane emissions from domestic animals, contributing 23,400 tonnes in 1990 and 25,700 tonnes in 2005.

7. Emissions from prescribed fires, oil production and distribution, mobile sources, incineration and stationary combustion sources are collectively small, contributing 51,900 tonnes in 1990 and 34,900 tonnes in 2005. This amounts to less than 10% of the total anthropogenic emissions for these years.

8. The annual uptake of methane in aerobic soils is estimated as approximately 41,000 tonnes. The possible error in this estimate could be high because of uncertainty in the understanding of the process and the base information.

9. The annual atmospheric uptake of methane by oxidation is estimated to be about 440,000 tonnes, with a range of 350,000 to 550,000 tonnes. Transport of methane to the stratosphere may represent less than 20% of the atmospheric oxidation sink.

10. The composite uncertainty in total anthropogenic methane emissions was estimated to be 19% using a simplistic analysis of precision error. This error

suggests 532,000 ± 100,000 tonnes for the anthropogenic emissions. The error in the natural emissions could not be estimated meaningfully because of lack of information about the error in the base data. The uncertainty in the natural emissions is expected to be higher than that for anthropogenic sources.

11. The greatest uncertainty in the estimates of methane emission exist for the natural gas industry, the oil industry and industrial landfills (wood residue and pulp mill residues). The following data gaps limit the accuracy of present estimates:

- Industrial landfills: — waste quantities in place;
  — emission rates;
- Natural gas industry sources — fugitive emission factors;
  — detailed inventories of equipment subject to fugitive leaks;
- Oil industry sources — fugitive emission factors;
  — detailed inventories of equipment subject to fugitive leaks.

12. Uncertainty exists in the estimate of emissions from municipal landfills because of lack of data on the rate constant, gas generation potential, the quantity of waste in place and the recovery efficiency of existing gas recovery systems. Improved data in these areas would allow better estimates to be made using the U.S. EPA landfill model.

13. The estimated cost effectiveness of methane control measures for major sources, calculated as the equivalent annual cost divided by the tonnes of methane emission reduction, is shown in table 6.

14. Landfill gas recovery systems are attractive for the following reasons:

- Methane emissions may be reduced by up to 90% with suitable design features;
- The recovered energy may be used to displace other energy supplies;
- Emission of odorous gases is reduced; and
- Problems with off-site migration of landfill gas are eliminated.

A significant potential exists for greater application of landfill gas recovery in the province. In addition, there is a provincial policy to reduce the volume of

material sent to landfill sites by 50% by the year 2000. The analysis in this study considered a system for a landfill with 450,000 tonnes in place in the first year of operation, increasing by 50,000 tonnes/year.

The economic viability of a landfill gas recovery system depends to a considerable extent on the gas price received and the gas cleanup required. At the gas price which could likely be attained in B.C., (presently on the order of $1.40 - 1.60/GJ), a landfill gas recovery system is not expected to be economically viable without some form of subsidy.

Table 6: Cost Effectiveness of Various Methane Control Measures

Control Measures	Cost Effectiveness ($/tonne CH_4 reduction)
Landfill Gas Recovery	
without gas sales	280
with gas sales	200
Manure Treatment	
Anaerobic digester with engine/generator set	1000
Aerobic digester	500
Degasification of Coal Mines	
10-yr amortization - without gas sales	150
- with gas sales	55
3-yr amortization - without gas sales	300
- with gas sales	205
Fugitive Emission Leak	
detection and repair programs	(99)* (for valves)
for processing plants	260 (for flanges)
(based on data for refineries)	680 (for pressure release valves)

* Cost savings shown in parentheses.

15. Methane emissions may be reduced by anaerobic or aerobic processes. The latter are more technically viable for on-farm application because they are easier, and less costly to operate and maintain. Aerobic treatment leads to a 70% reduction in methane emissions for a dairy farm. Although no valuable products are generated by such systems, there is a reduction in odours and water quality impacts.

16. Degasification of coal mines to reduce methane emissions appears attractive because of the large quantities of methane involved and the proximity of the energy load of the mine operations. However, the technology for coal degasification for B.C. mines is not proven. A detailed study is needed to ascertain the technical and economic viability of such a control measure.

    The main obstacles to successfully using degasification are the shallowness and complex geology of the coal deposits, as well as the logistics of degasifying the coal before mining. Development of coal degasification technology in B.C. for application elsewhere in the world is worth consideration — for coal deposits having high emissions and more suitable characteristics.

17. Methane emissions from natural gas production, processing and distribution could be reduced by actions which reduce fugitive losses — the most common being "leak detection and repair" (LDAR) programs. At this point, data on the effectiveness of LDAR for natural gas facilities is not available because the studies on LDAR uses have focused on petroleum refineries and organic chemical plants.

    There is a potential in some facilities for LDAR to be economic or, at least, be relatively cost effective. The cost of LDAR can be expected to be much higher when applied to remote facilities compared to a large centralized facility.

    LDAR programs are included in the NO_x/VOC management plan for refineries and organic chemical plants. A code of practice is being developed for fugitive emissions from these facilities, which will include large gas plants. This code will help to identify maintenance and operating practices and performance standards that reduce methane emissions. Studies are underway to improve the understanding of fugitive emissions from the natural gas sector.

    It is clear that more work is necessary to determine the specific control measures for subsectors in the natural gas industry. A detailed study of model facilities is needed — with details of the number and types of equipment, natural gas volumes, pressures and other similar data to determine methane reduction estimates and costs of control.

18. A reduction in methane emissions could be achieved by a wide variety of actions that conserve energy, make energy use more efficient, or convert residues to energy. These measures can reduce methane emissions from energy conversion equipment and waste disposal, as well as the whole fuel production and distribution network.

19. Methane emissions can be decreased by reducing the quantities of biodegradable wastes disposed of in landfills or, in the case of wood residue, disposed of in beehive burners. Phasing out beehive burners and using alternate incinerators or energy systems with more efficient combustion will also reduce methane emissions.

20. Economic and other kinds of incentives, as well as regulations, have the potential for reducing methane emissions These measures include taxes on high emitters; rebates for low emitters; emission fees; emissions trading; and command and control strategies. Each has advantages and disadvantages, as discussed in the report. A detailed study of these options would be needed in the context of specific source sectors and subsectors to determine the costs and degree to which methane emissions could be reduced.

21. The consultant developed a master list of potential control measures. The subcommittee then selected control measures from the master list as reasonable for implementation in the short and long term, considering economics and social impacts.

A 13% reduction in anthropogenic methane emissions was estimated in the short term (< 3 yrs). A 27% reduction in anthropogenic emissions was estimated in the long term (> 10 yrs), relative to emissions in 2005. The net emissions after control (412 kt) in the long term were found to be 23% lower than those estimated for 1990 (533 kt). No control measures were considered for natural emissions sources.

The most important source sector for applying controls is landfills, because it is the dominant emission source. The control measures considered for this source sector include landfill gas recovery and reducing the quantities of wastes landfilled.

D. Recommendations

1. Economic barriers to installation of landfilled gas recovery systems should be reviewed.

2. A methane emission model should be developed and verified using landfills in B.C. that operate landfill gas-recovery systems. The model would be used to analyze the economic viability of recovering methane at major landfills in the province.

   Data from existing landfill gas recovery systems can be interpreted to determine the appropriateness of the Scholl Canyon model for use in B.C. — and to develop default values for the model input parameters.

3. Existing regulations for municipal and industrial landfills should be reviewed and revised, as appropriate, so that they yield landfills well suited to landfill gas recovery or similarly effective methane control.

4. Alternatives to incinerating and landfilling wood residues should be developed — such as reducing residue generation, along with using residues as fuel or to produce wood products and pulp.

5. A code of practice should be developed for the owners/operators of natural gas production, processing and transmission systems.

6. A detailed study of methane emissions from the natural gas production, processing, transmission and distribution system should be undertaken. The study should quantify emissions and determine the cost effectiveness of control measures.

7. A detailed study should be undertaken of the cost and effectiveness of economic incentives for methane emission control.

8. Use of aerobic or anaerobic manure treatment systems on dairy farms should be encouraged.

9. A more in-depth analysis should be done to determine methane emissions from landfills of wood residue and pulp mill residues — because of the uncertainty in the preliminary estimates made in this study.

4

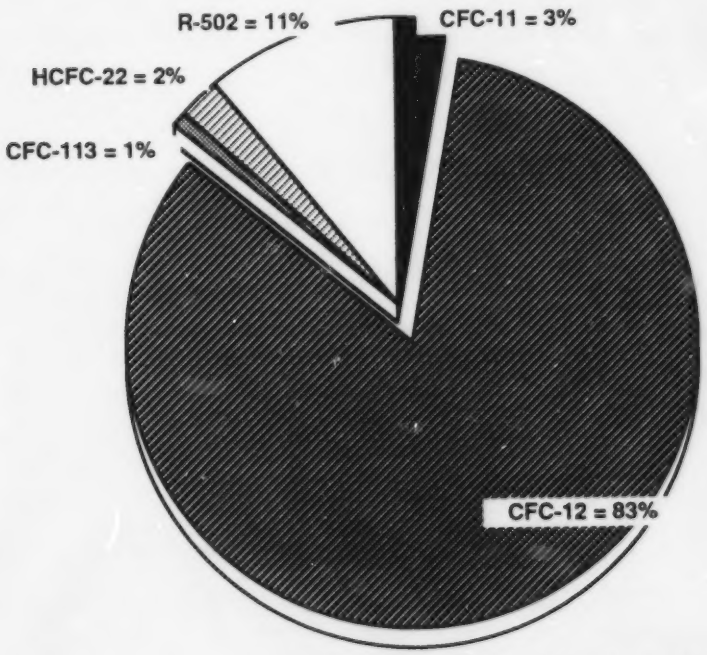
OZONE-DEPLETING GREENHOUSE GASES

A. Introduction

This chapter is based on the consultant's report prepared by Peat, Marwick, Stevenson and Kellogg Management Consultants. It was published in April 1992 and is available from Crown Publications. It represents the state of this rapidly changing field as of June 1991.

Chlorofluorocarbons (CFCs), unlike other greenhouse gases, are not produced naturally. Each molecule is approximately 1,000 to 7,000 times more active as a greenhouse gas than CO_2.

Figure 6: DISTRIBUTION OF MAJOR CFCs IN BC



Calculated Relative to the Greenhouse Warming Potential of CFC-12

Substitutes for CFCs are coming on the market, and it is hoped that new emissions of CFCs will be all but eliminated in the near future. However, the extremely long lifetime of CFCs (60 to 400 years) means that they will remain in the atmosphere contributing to global climate change well into the next century. Recent inventory data (figure 6) indicate that CFC-12 emissions are the major CFC contributor to global warming in British Columbia.

B. Overview

This report investigates possible control options for the various industrial sectors in which CFCs, halons, methyl chloroform, carbon tetrachloride and hydrochlorofluorocarbons (HCFCs) are used. In addition, emission control policies are reviewed for each of these sectors. The report also provides an assessment of possible management options for British Columbia.

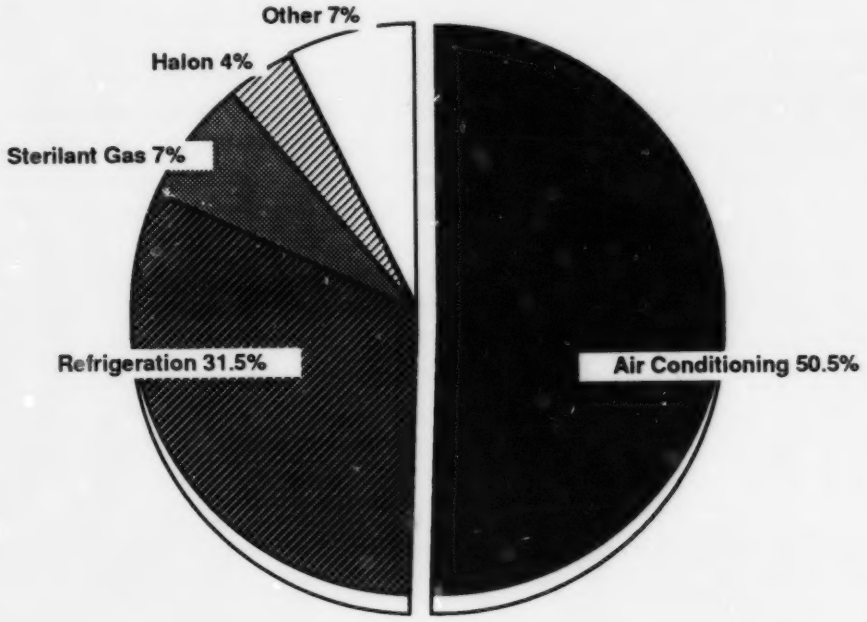
The approach followed in this assessment was to provide an analysis of likely control options and emission control policies by application. In other words, they provide information, by industry type, on the approaches that are being followed to reduce the use of these substances and to control emissions. This information provides a necessary starting point in considering what further control policies may be desirable.

The report provides a review of control options and emission controls under the following headings:

- Refrigeration and air conditioning;
- Flexible foams;
- Rigid foams;
- Sterilant gas;
- Solvents;
- Halons;
- Methyl chloroform;
- Carbon tetrachloride; and
- Hydrochlorofluorocarbons.

The role of emission of CFCs and related chemicals from various sectors in British Columbia is shown in figure 7.

Figure 7: 1990 Emissions of CFCs and Related Chemicals as Greenhouse Gases



Refrigeration and Air Conditioning

The refrigeration and air conditioning industry is working closely with suppliers in developing and testing systems based on alternative refrigerants. These refrigerants are HCFC-123 for CFC-11 and HFC-134a for CFC-12. On the air conditioning side, units using HCFC-123 are now commercially available. Commercial quantities of HCFC-134a are also available now, but the transition schedule is somewhat slower for CFC-12.

As shown in figure 8, the largest single source of CFC-12 emissions (and the most serious CFC in terms of a greenhouse gas in British Columbia) was determined to be automotive air conditioners. HCFC-22, a much less potent contributor to stratospheric ozone depletion, can be used in many air conditioning and refrigeration applications.

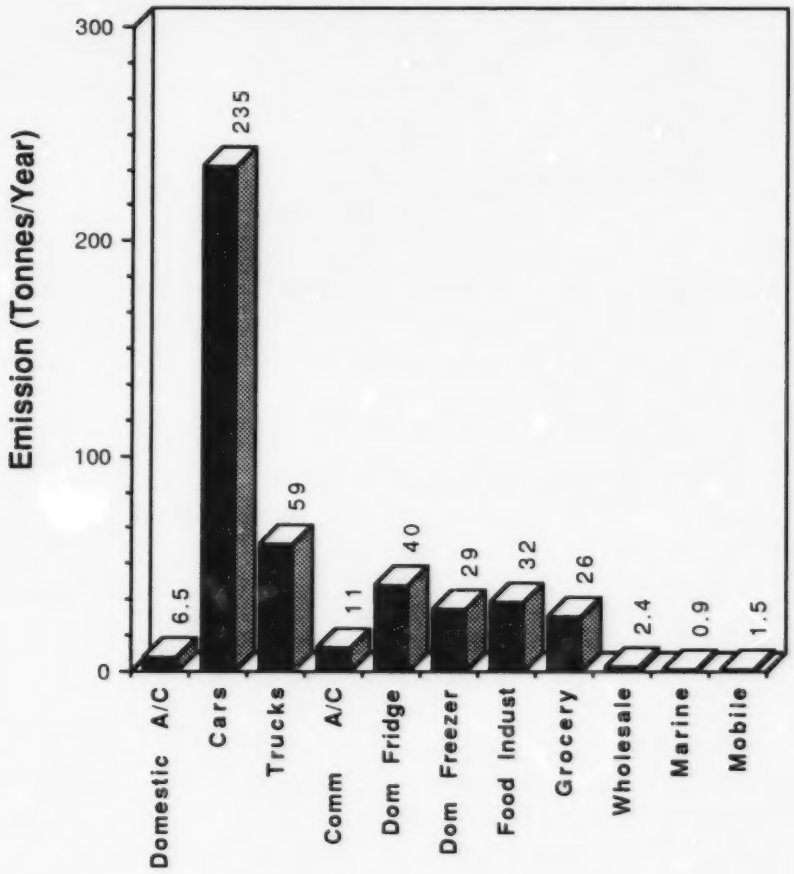
A variety of emissions controls are feasible and are being developed in this sector. Better design of equipment; improved installation and operating procedures; better

servicing and repair methods; and new recycling and disposal approaches are all being implemented. This is one of the sectors in which the returns to better emission controls are greatest. Industry codes of practice are making improvements, but there remains an important role for public policy — particularly in the area of recycling.

Flexible Foam

Flexible foam is used as a cushioning material and is produced either as a slabstock or as a moulded product. Most of the CFC-11 that is used in this sector is to produce specific foam grades. These grades are low density foams and soft high density foams.

Figure 8: Major Uses of CFC-12 in B.C.



The most important control options in this sector are alternative blowing agents and new polyols that can produce the desired foam grades without the use of an auxiliary blowing agent.

Emission controls are technically feasible but could be used effectively only in smaller plants with vertical foam chambers.

Rigid Foams
The use of CFCs in this sector is to produce polyurethane foam, extruded polystyrene foam and phenolic foam. Alternative insulating materials, namely fibreglass, are competitive in some applications and constitute a control option. The other options are new blowing agents and new polyol systems.

In the production of extruded polystyrene insulation, most production has been converted to a blend based on HCFC-142b. In the polyurethane sector, the alternative blowing agent is likely to be HCFC-123 or HCFC-141b. For phenolic foam, options include HCFC-123, HCFC-141b and HCFC-142b.

The nature of the production process for these foams makes emission controls technically feasible, but not economically viable. These products are all closed cell, and the trapped CFCs play an important role in the properties of the product. The intent is to capture as much of the blowing agent as possible in the board so that emissions are already limited.

Sterilant Gas
CFC-12 is used as a diluent in hospital sterilant gas for use in applications where sensitive materials such as polyvinylchloride cannot be exposed to the heat of steam sterilization. Control options include the use of HCFC diluents, recycling and the use of other sterilization techniques.

Emissions controls are feasible and can be introduced with machines that now use CFC-12. These will be compatible with new HCFC units.

Solvents
CFCs are used in a variety of cleaning applications including the electronics sector where circuit boards and other components are cleaned prior to final assembly. A variety of control options are being pursued to reduce consumption of CFC-113. Better conservation practices can play an important role, along with alternative cleaning technologies like aqueous cleaning or no-clean fluxes.

In all areas of solvent cleaning, firms are moving to tighter cleaning systems to reduce emissions. Much progress has been made in this area in dealing with CFCs. As new cleaning systems are introduced, some of these will uses HCFCs, and controlling emissions more effectively should be an objective of this transition.

Halons
Halons are the most serious ozone-layer depleter emitted in British Columbia. They have been used extensively both in portable fire extinguishers and fixed fire-suppression systems.

Sales of both types of units have declined substantially since 1990. Alternative extinguishing agents, such as dry chemical or CO_2, have been used in areas where the properties of halons are not essential. Commercial testing is now taking place for substitutes for halon 1211 and halon 1301 that are more of a drop-in replacement.

For emission controls, most of the potential gains are for 1301 systems. Improved practices have already been implemented for discharge testing, filling, shipping and service. Effective management of the existing stock of banked halons can contribute to reduced emissions and to more effective use of the halons that are already in place.

Methyl Chloroform
Methyl chloroform is used widely as an industrial solvent because of its low toxicity, low volatility and low flammability. No single alternative will replace its use in the applications where it is now used. Control options are similar to those for CFC-113. Tighter cleaning systems, no-clean technologies, aqueous and semi-aqueous cleaning and HCFC solvents are all likely to play roles in this area.

Emission reductions are likely to be observed as a result of better conservation practices and new cleaning systems that minimize the loss of solvent.

Carbon Tetrachloride
Carbon tetrachloride is used as a catalyst promoter in oil refining and to remove nitrogen trichloride in the production of chlorine. Emissive uses are quite limited and available data indicate that substitutes can be used for this chemical.

Hydrochlorofluorocarbons
As noted throughout the preceding subsections, HCFCs will replace CFCs in a variety of applications. The HCFCs are bridging substances that will ultimately be controlled under the Montreal Protocol. Control options for these substances are not clear at this point, but many emission control policies developed for CFCs will be effective for HCFCs as well.

C. Management Options For British Columbia

Overview

This section sets out the policy implications for British Columbia of the control options review and the assessment of emission control strategies. In it, we provide an outline of how BC Environment can contribute most effectively to emissions reductions in the province.

In developing management options for the province, some assumptions were required as to the criteria to be used in assessing those options. The scope of the project was not intended to include a complete socio-economic evaluation, but cost and other considerations would have to be taken into account for our report to be of value.

In developing the management options in this section, the factors incorporated in the analysis are:

- Phase-out dates for CFCs and the extent of HCFC replacement;
- Demands for recycled material;
- Costs of options to consumers, industry and to government for administration;
- Enforceability — including expected compliance;
- Acceptability by the public or specialized groups such as insurers in the case of halons; and
- Compatibility with other regulations.

With respect to priorities, government should focus on the "three Rs" — reduction is the first priority, followed by reuse and recycling. At the same time, all levels of government should make a commitment to leading by example. With the development of progressive purchasing policies, requirements for service contractors, and so on, government will be in a strong position to develop and implement appropriate regulations with industry.

Approaches for Reducing Consumption

The intent of the management options being considered in this section is to contribute to an accelerated schedule of consumption reductions and to reduce emissions on a continuing basis. As indicated above, a number of factors must be taken into account in developing these options. The first step, therefore, is to apply

these criteria and decide on the sectors that will be regulated and the extent of regulation. The sequence of events to accomplish this is:

- Determine if sector is to be regulated;
- Develop information-reporting requirements and forms to establish baseline quantities;
- Establish sectoral consumption reduction schedules;
- Develop monitoring framework to ensure compliance with reduction schedules;
- Develop regulations to support these regulatory initiatives; and
- Promote education and training programs as needed.

Our assessment is that the most important factor in determining effective policies for British Columbia is the extent to which industry sectors are reducing consumption and emissions under the existing regulatory framework. The federal Minister of the Environment has announced the following phase-out schedule for CFCs:

- Eliminate by 1995 in rigid foams;
- Eliminate by 1993 in flexible foams;
- Eliminate by 1995 model year in automobile and light truck air conditioning;
- Eliminate in solvent cleaning applications by 1994; and
- Eliminate in sterilant gas by 1994.

In addition, Environment Canada has drafted regulations limiting the use of halon 1211 in portable fire extinguishers with exemptions for certain critical uses. What are the most useful policy approaches to support this regulatory framework that is already in place?

The most obvious starting point is to focus on exclusions from the list shown above. There is no substance-specific timetable for any of the following:

- Most of the refrigeration and air conditioning sector;

- Halon 1301 systems;
- Methyl chloroform; and
- Carbon tetrachloride.

In addition to this list, it may be useful to consider the rigid foam sector for more careful scrutiny. The existing federal initiative treats this as a single sector, but as the analysis in this report has shown, this is not correct. There are essentially three subsectors to deal with here, and each has a different planned reduction schedule.

The 1995 date may be quite appropriate for polyurethane foam, particularly in poured and sprayed applications, but extruded polystyrene and phenolic foam can meet a more stringent schedule. The evidence that we have accumulated suggests that producers of these latter two foams can complete their plans to replace CFCs during 1993. British Columbia's single largest foam manufacturer has already switched its polystyrene plant to an HCFC-22 system.

In addition, it may be useful for the provincial government to develop an approach to meeting the federal target for sterilant gas. The problem here is concentrated within the hospital sector. A joint committee including representatives from BC Environment, the Ministry of Health and the hospital community could assist hospitals in British Columbia in reducing consumption more quickly.

Develop Reporting Requirements

To support the development of sectoral consumption-reduction policies, the most important standards to develop relate to reporting on use patterns. This highlights the importance of selecting sectors to regulate carefully.

Reporting on consumption by individual users in sectors imposes a significant regulatory burden on the private sector and also involves substantial public sector costs. However, if regulations of this kind are to be implemented, baseline quantities for each user must be established. Consumption reductions must be monitored annually relative to this baseline and the sector reduction schedule.

In this project, we have developed estimates of consumption within sectors. In some cases, we have obtained data from users directly. However, it has not been possible within the scope of this project and on a purely voluntary basis to establish a complete inventory. Some users, in fact, refused to provide data. A regulatory requirement appears to be the only way to get the data that would be needed for regulatory purposes.

Develop Sectoral Reduction Policies

Assume that the base-year data collected as described above are for 1991. The data

would be in terms of the consumption of specific CFCs, and the firm would then be assigned a baseline consumption quantity. To be consistent with the Montreal Protocol, this baseline quantity should be defined in ozone-depletion potential (ODP) units — meaning that it would be the sum of each quantity of CFC multiplied by its ODP. For example, if a firm used 10 tonnes of CFC-12 with an ODP of 1.0 and 10 tonnes of CFC-113 with an ODP of 0.8, its consumption baseline would be 18 tonnes measured in units of ODP.

Based on an assessment by BC Environment of how stringent regulations within the province should be, a reduction schedule would be developed ending with the year of complete phase-out. As a hypothetical example,the schedule for rigid polystyrene insulation foam might involve a reduction to 60% of 1991 consumption in 1992, 30% in 1993, and zero thereafter.

Schedules of this kind should be developed in consultation with users in each sector to assess more clearly the costs associated with differing degrees of stringency. Note that schedules relate to sectors rather than substances (e.g. CFC-12) because technically feasible reduction schedules are sector-specific.

Initiatives in Provincial Ministries and Related Institutions

In the area of ozone-depleting greenhouse gases, the federal, provincial and municipal governments can play a key role in dealing with both consumption and emissions in the province by establishing themselves as model institutions. Such an approach has already been taken by some firms in the private sector, which have announced a corporate commitment to the earliest possible elimination of these substances.

Results can be more immediate when implemented by the appropriate level of government within its own jurisdiction and will support whatever regulatory initiatives are developed for the private sector. As well, there may be some direct spillover benefits if particular policies developed by government can be used as well by the private sector.

The broad outline of such a provincial strategy can be described in terms of the following points:

- Define units within which responsibility for policies is to be assigned. For example, the Ministry of Education would be responsible for developing a program within the ministry itself, but would also require the units that it supports (such as school boards) to do the same;

- Develop a detailed assessment within each unit of consumption, and banks of ozone-depleting substances. New construction and the types of insulation to be used could be specified. Policies for dealing with used

refrigerators, and policies of dealing only with air conditioning and refrigeration contractors with recycling facilities, would promote the growth of such facilities.

Halon portable fire extinguishers (1211) are presumably no longer being purchased but many are certain to be in the existing inventory in many areas. Evidence from other jurisdictions shows that there will be many such units in service where other types of units would work as well. These units could be retired so that no emissions result — and recycled for essential aviation uses or destroyed. We are not aware of any such systems in operation at this time;

- Develop specific plans and timetables within each of these units to be "CFC-free," with similar programs for the related substances; and

- Develop a reporting system to BC Environment so that progress can be monitored. The results can then be reported to other users — to demonstrate the progress that can be made with such programs.

There are clear benefits of such initiatives in a variety of dimensions. Whatever regulatory strategies are proposed, they will be more palatable if the government first shows the resolve to put its own house in order. In the area of recycling, government can provide direct results. It can also support the recycling industry by contracting only with firms that are committed to and have invested in the necessary types of recycling equipment.

Government, government agencies and firms regulated by government such as B.C. Hydro and B.C. Tel have been major purchasers of halon fire protection systems. Some essential uses may remain, but standards are necessary to ensure that other fire protection alternatives are used wherever possible. Systems that are now in place where alternatives are feasible can be dismantled, and the halon 1301 can be recycled for use in essential areas elsewhere. This will reduce the quantity of new halon being installed in the province.

Codes of practice have been described elsewhere in this report for refrigeration and air conditioning. This approach can also be applied in the fire protection area. The fire protection community is already active in this area in some jurisdictions (e.g. recapture of halon 1301 in decommissioned systems in Ontario and British Columbia). These initiatives can be reviewed for their adequacy.

Develop Recycling Initiatives

This section assesses potential management options in the area of reclamation and recycling. Based on current technology, these activities could be carried out in many areas. Here, we focus primarily on areas where cost effectiveness is the greatest. We

recognize that efforts to establish such initiatives are already in progress through a joint federal-provincial group, but effective provincial policies will not be inconsistent with these initiatives.

Effective policies on reclamation and recycling offer several advantages with respect to controlling ozone-depleting greenhouse gases:

- They help reduce both consumption and emissions;
- They contribute to achieving more stringent reduction targets;
- They are essential to meeting service demands after phase-out; and
- As production declines and is ultimately phased out, the benefit-cost picture for recycling becomes increasingly favourable.

The areas in which reclamation and recycling policies can be implemented most successfully are:

- Refrigeration and air conditioning;
- Halon 1301 systems;
- Solvents; CFC-113 and methyl chloroform; and
- Sterilant gas.

Previous sections of this report have dealt in more detail with the potential role for recycling in each of these sectors. An area like sterilant gas has significant potential in this respect because so much of current consumption occurs in provincial hospitals. In this section, however, we focus primarily on refrigeration and air conditioning. This is because the quantities are so large in this sector that recycling initiatives will have the greatest benefits here.

In the refrigeration and air conditioning sector, recycling initiatives appear necessary if plans for early phase-outs of CFCs are to be achieved without generating very high costs. As an example, consider the phase-out date for CFCs of 1997 (*editor's note: This date was recently advanced to 1995.*) that has been announced by Environment Canada. New equipment that is being installed now contains CFC refrigerants. This will likely continue for new residential refrigerators, for example, until 1995. How will units charged with CFC-12 purchased new in 1995 and requiring service in 1998 be repaired? After new production is phased out, the answer must be that these units are serviced with reclaimed CFC-12 that has been recycled.

Table 7: Life Spans of Refrigeration and Air Conditioning Equipment

Equipment Type	Lifespan (years)
Domestic refrigeration	12
Mobile air conditioning	8
Refrigerated transportation	12
Industrial refrigeration	20
Commercial chillers	20
Cold storage/food refrigeration	15
Retail refrigeration	8

Source: *Refrigeration, Air Conditioning and Heat Pumps Technical Options Report*, (UNEP, 1989).

The dimensions of the service demand problem following production phase-out for new CFCs is shown in table 7. This exhibit shows estimated life spans for various types of refrigeration equipment. Depending on the specific assumptions that are made about the pattern of installing CFC-using equipment before 1997 (*editor's note: this date has been advanced to 1995.*), service demands could be substantial and could continue for nearly 20 years. If adequate supplies of recycled CFCs are not available, the costs of scrapping this equipment prematurely will be very high. The potential benefit of effective measures in this area (e.g. recycling) should make this an attractive policy for the British Columbia government to implement.

One perspective on how a CFC reclamation/recycling program could be operated is provided in the report prepared by the Federal-Provincial Working Group on Controls Harmonization, entitled *National Action Plan for Recovery and Recycle of CFCs*. The report is directed primarily to refrigeration and air conditioning, but the principles are applicable to other areas as well. In this plan, the essential steps are:

- Develop the appropriate incentive and regulatory structure to promote recovery and recycling;
- Create an adequate infrastructure to contribute to reclamation, transport, recycling and disposal of CFCs; and

- Develop an information and training program to provide support from the public and to develop the capacity in the CFC service sector to carry out an effective program in this area.

Although initiatives in this area are already in progress, it is our understanding that there is no commercial facility in British Columbia to recycle reclaimed CFCs in large quantities. Small machines are available, as are "vampire" units that recycle on-site. Various jurisdictions have developed regulations dealing with recycling, but there is not yet a single model that can be applied directly. The data on banked quantities in the companion volume to this report provides a useful starting point in developing a recycling strategy for British Columbia.

Editor's Note:

1) *BC Environment has developed draft regulations for the control of ozone-depleting substances. These have been circulated to stakeholders for review, and are undergoing revision based on stakeholder comments.*

2) *Recent research* (Nature, *vol. 356, 9 April 1992) indicates that primary aluminum production produces CFC-14 (CF_4) and CFC-116 (C_2F_6). These gases, though not considered in our inventory or by the IPCC, are extremely long lived (10,000 years) and have a very high global warming potential (10,000 times that of CO_2). These compounds are not covered under the terms of the Montreal Protocol because they play no role in ozone layer depletion.*

   Production figures for the aluminum smelter at Kitimat indicate that approximately 272 kt (1990) of primary aluminum are produced annually. Using a conversion factor of 2.0 kg of CFC-14 and 0.2 kg of CFC-116 per tonne and a total greenhouse warming potential of 10,000, this yields a CO_2 equivalent of approximately 6000 kt. These calculations, though relatively crude, indicate that this source of CFC emission in British Columbia is almost 150% larger than the entire CFC emissions recorded in our inventory to date — and requires additional study.

5

NITROGEN OXIDES, VOLATILE ORGANIC COMPOUNDS AND OZONE AS GREENHOUSE GASES

A. Overview

This chapter is based on the consultant's report prepared by Concord Environmental Corporation, published in April 1992 and available from Crown Publications.

Recently published data by the Intergovernmental Panel on Climatic Change indicate that over 100 years, NO_x will contribute 6% and nitrous oxide (N_2O) 4% of total potential global warming. Volatile organic compounds (VOC), non-methane hydrocarbons, will contribute 0.5% to the total effect. These impacts of NO_x and VOCs are calculated on the basis of their contribution to the formation of ground-level ozone, which is a greenhouse gas in its own right.

Nitrous oxide has a lifetime of 150 years and a global warming potential, after 100 years, of 120 times that of CO_2. Human sources of N_2O include, fossil fuel combustion, biomass burning, fertilizers and cultivated natural sources.

B. Background

This project, namely, the British Columbia Emission Inventory of $NO_x/VOC/O_3$ as Greenhouse Gases, was carried out under contract to BC Environment on behalf of the Greenhouse Gases Steering Committee. The fundamental objective of this study was two-fold:

- Compilation of **$NO_x/VOC/O_3$ emission inventory**; and

- Recommendation of **management measures** for reduction of $NO_x/VOC/O_3$.

C. $NO_x/VOC/O_3$ Emission Inventory

Consistent with the broad scope of strategy development for greenhouse gas management at this early stage, the NO_x/VOC portion of the inventory was developed around the existing Environment Canada Residual Discharge Information System (RDIS) for base year 1985, since most of the information required was contained in RDIS.

Similar data in the BC Environment/GVRD Lower Mainland Emission Inventory (LOMEI) allowed the preparation of an integrated inventory of these species for the Greenhouse Gases Project. The principal additions of new data to the existing RDIS/LOMEI databases were:

- Nitrous oxide (N_2O) from anthropogenic and biogenic sources; and
- VOCs from biogenic sources.

The study also involved identifying possible management measures, as well as evaluating them. The overall purpose was to assess which measures may be readily implemented/adopted and which may require more proactive actions by the provincial government.

Inventory Results

When the results of the inventory are expressed in terms of carbon dioxide equivalents, using the Global Warming Potentials given in an Intergovernmental Panel on Climate Change report (figure 9), the total anthropogenic emissions of NO_x, N_2O and VOCs in B.C. are a minor fraction of the province's total CO_2 emissions. The total anthropogenic emissions of the gases inventoried for this project are about 7,300 kilotonnes per year (1985). NO_x, N_2O and VOCs make comparable contributions, and transportation is the major contributor to these emissions (50%).

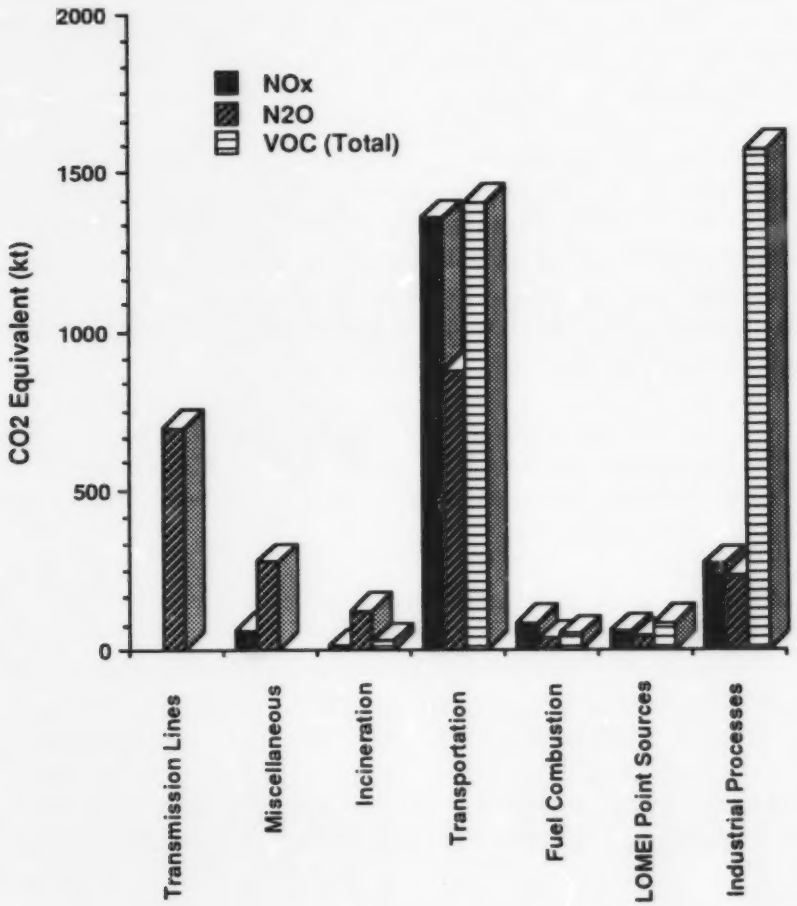
These numbers are to be compared with CO_2 emissions for B.C. of 84,000 kilotonnes (1988). That is, the anthropogenic $NO_x/VOC/O_3$ emissions as greenhouse gases are equivalent to about 9% of the CO_2 emissions in the province. These results are summarized in table 8.

If the use of the Global Warming Potential factors developed by the

Intergovernmental Panel on Climate Change is reliable (which has not been assessed), it appears that the gases inventoried for this project play a minor role as greenhouse gases.

The global importance of CO_2 (estimated 61% of warming potential over 100 years) is about ten times that of NO_x, N_2O and VOCs combined (about 6% of warming potential over 100 years), according to an Intergovernmental Panel on Climate Change report. The data reported here imply that CO_2 is also about 10 times as important as $NO_x/N_2O/VOC/O_3$ in B.C..

Figure 9: Major NO_x/VOC/O_3 Emission Sources in B.C.



The role of NO_x/VOC/O_3 as greenhouse gases is clearly much less than that of CO_2 itself. However, the importance of this issue to developing the overall management strategy for anthropogenic emissions suggests that the validity of this approach, based on Global Warming Potential, should be reviewed. The general consistency of the ozone emission quantity derived using both the Intergovernmental Panel on Climate Change approach and an alternate method of estimation with existing air quality data supports the validity of the approach.

D. Summary of Management Measures

The review of management measures was based on NO_x/VOC and general air quality plans in other jurisdictions. The review of management measures focused on the largest source sectors for NO_x/VOC/N_2O: road transportation; off-road transportation; transmission lines; slash burning; kraft pulping. These five sources account for about 70% of total emissions in the province. These results are summarized in the following table 8.

Because road transportation accounts for about 41% of provincial emissions, many of the most important management measures lie in this sector. For example, increased fuel efficiency standards, inspection and maintenance programs, and reduced gasoline volatility are the most promising measures identified in this review. All three have the potential to reduce emissions by more than 30 kilotonnes CO_2 equivalent annually, at relatively low cost and with few barriers to implementation.

Collectively, these three measures could reduce emissions by about 225 kilotonnes per year (based on estimates for the Lower Fraser Valley). Other road transportation measures raise trade-offs between abatement potential and cost/barriers to implementation (including lifestyle changes).

Alternative transportation fuels have received considerable attention in the literature. However, based on the review conducted for this study, the overall effect on NO_x/VOC emissions is inconclusive; generally, VOC emissions appear to be lower for alternative fuels but NO_x emissions could be either higher or lower. The net effect is too unclear to recommend fuel switching as a management measure.

There is considerably more uncertainty surrounding management measures in other sectors. For example, a blanket policy to restrict slash burning is inappropriate

Table 8:

SUMMARY of NO_x / VOC EMISSIONS as CO_2 equivalents for British Columbia (1985)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Anthropogenic					
1. B.C. Total	1854	2285	2276	854	7270
2. B.C. Total Industrial Processes [1]	333	276	471	177	1257
B.C. Industrial Processes	272	232	409	153	1066
B.C. Fuel Combustion	85	36	36	14	171
B.C. Transportation	1355	876	1024	384	3639
B.C. Incineration	18	125	19	7	169
B.C. Miscellaneous	63	142	699	262	1166
B.C. Open Sources [2]	0	0	27	10	37
3. LOMEI Industrial Point Sources	61	41	62	23	187
4. Fertilizer Application	0	96	0	0	96
5. Anaesthetics + Aerosols	0	43	0	0	43
6. Transmission Lines [3]	3	693	0	0	693

Notes

1 Includes BC Industrial Processes and LOMEI Industrial Point sources

2 Excludes forest fires which are considered to be a biogenic source

3 Major Transmission Lines are estimated to contribute minor amounts of ozone and NO_x (1-3 kT CO_2 equiv.) in addition to N_2O

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

Table 8:

SUMMARY of NOx / VOC EMISSIONS as CO2 equivalents for British Columbia (1985) (Cont'd)

SOURCE	$NO_x(O_3)$[a] (kt)	N_2O (kt)	VOC (O_3)[b] (kt)	VOC (CO_2)[c] (kt)	Total (kt)
Biogenic					
1. B.C. Total Biogenic	355	11818	20578	7717	40468
2. B.C. Vegetation	0	0	20077	7529	27606
3. Soils	250	10196	0	0	10446
4. Forest Fires	81	151	500	189	921
5. Marine Waters	0	1456	0	0	1456
6. Lightning	24	17	0	0	41

Notes

a CO_2 equivalent of ozone produced from NO_x through atmospheric photochemistry

b CO_2 equivalent of ozone produced from VOC/NMHC through atmospheric photochemistry

c CO_2 produced from VOC/NMHC by atmospheric oxidation

given the variability of site characteristics in the province. Rather, promotion of site-by-site analyses, with emissions reduction explicitly taken into account in silviculture prescriptions, is suggested.

Apart from NO_x standards for industrial boilers, emissions reductions in kraft pulping may require significant process changes that could also have serious implications for markets and competitiveness. Further empirical work concerning the magnitude of N_2O emissions from transmission lines is called for, although cost and revenue concerns create incentives to reduce corona and line losses and, hence, N_2O emissions.

Additional emission reductions could be achieved through a variety of measures related to solvents, surface coatings, and gas and diesel marketing, although some of these options are costly.

For those road transportation and other measures for which estimates were available, total abatement potential amounts to some 635 tonnes CO_2 equivalent per year, or less than 10% of total anthropogenic emissions of NO_x/VOC/O_3 in the province.

As noted in the text, the list of possible management measures does not constitute a management strategy. In determining a strategy, NO_x/VOC measures must be considered within the context of other pollutants of concern. In some instances, there may be complementarity between measures, but in other cases, conflicts may arise. In some instances, cost effectiveness may favour some measures over others. Another important aspect of a management strategy is to select the most appropriate policy tool or tools to implement the selected set of measures. These tasks will be part of the integration of all four components of the Greenhouse Gases Project.

E. Conclusions

There are several main conclusions to be drawn from the above discussion.

1. The estimated contribution of the N_2O and O_3 documented in this inventory to the overall greenhouse gas emissions from sources in B.C. is a small fraction of the CO_2 emissions.

2. NO_x and VOCs have about the same indirect global warming potential, apparently, so that the strategy for their control for other reasons, such as to reduce ground level ozone formation, is not influenced by their behaviour as greenhouse gases. In fact the strategies are

complementary.

3. N_2O contributes a minor portion of the overall greenhouse gas emissions in the $NO_x/N_2O/VOC/O_3$ inventory and is, therefore, of relatively minor importance for consideration of management measures.

4. The previous conclusions suggest that the objectives of managing the $NO_x/VOC/O_3$ portion of the overall greenhouse gas issue are essentially congruent with those of NO_x/VOC management for control of peak ground level ozone levels (the National NO_x/VOC Management Plan). Control of these gases will produce a "greenhouse bonus."

5. When the abatement objectives of the NO_x/VOC Management Plan are expressed in terms of CO_2 equivalents, the collective contributions of the most probable reduction measures for anthropogenic emissions will be about 10% of the total greenhouse impact of the anthropogenic $NO_x/VOC/O_3$ emissions. This estimate includes both high and low cost options.

6. The single most effective measures are that are known to have relatively low costs and low barriers to implementation lie in the road transportation sector. These measures include reduced gasoline volatility, tighter emission standards for motor vehicles, and an inspection and maintenance program for vehicles.

7. It is obvious, but bears repeating, that all of the possible management measures for $NO_x/VOC/O_3$ as greenhouse gases must be considered in the context of the management measures for the other classes of greenhouse gases, especially CO_2, and also in the context of the National NO_x/VOC Management Plan.

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FOR MORE INFORMATION:

For British Columbia:

Contact:
Air Resources Branch
Ministry of Environment, Lands and Parks
2nd Floor
777 Broughton Street
Victoria, B.C.
V8V 1X5

Telephone: (604) 387-9933
Fax: (604) 356-7197

Callers from outside Victoria can use the toll-free number:
1-800-665-7120 (Consultation Project)

Crown Publications Inc., 546 Yates Street, Victoria, B.C., V8W 1K8,
Phone (604) 386-0221.

For the Greater Vancouver Regional District:

Contact:
Air Quality & Source Control Department
Greater Vancouver Regional District
4330 Kingsway
Burnaby, B.C.
V5H 4G8

Telephone: (604) 436-6750
Fax: (604) 436-6707